Fabrication of multi-functional calibration standard for image processing microscopes

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Measurements are carried out to investigate the limits of confocal microscopy and white light interferometry using selected structures made out of silicon (e.g. edges, spheres). First results of a numerical model of the confocal microscope are presented which will be used in further work to determine an appropriate choice of the calibration standard. A hot emboss was used for low-cost reproduction of the silicon structures.

1 Motivation

Confocal microscopy and white light interferometry have become powerfull tools to characterise structured surfaces. While there exist suitable standards and calibration probes for conventional tactile metrology systems, the traceability of optically acquired data is difficult to manage due to specific physical limitations of the optical systems.

To gain an insight into the physical effects that limit the optical devices a numerical model has been developed. The calibration standard is being designed using this model.

The aim of this project is to provide a multi-functional (suitable for different optical systems) calibration standard. To realise this standard different geometries are to be produced using silicon. For reproducing the standards economically the silicon structures are to be hot embossed into plastic.

For abbreviation a detailed description of the confocal microscope and white light interferometer are not given here but can be found in [1].

2 Physical limits of the imaging system

The confocal microscope as well as the white light interferometer is limited due to the finite numerical aperture (NA) of the objective. This can be understood by using a simple geometrical model which is shown in figure 2.1 [1]. The probe in figure 2.1 is a plane reflecting surface. The surface normal is tilted with respect to the optical axis of the objective by an angle ϕ. If the tilt angle ϕ exceeds a critical angle none of the light is reflected back into the objective. To investigate this fact, measurements were carried out using an optical rough glass sphere. A confocal microscope (Nanofocus) with a numerical aperture of 0,8 was used for this purpose. The results show that the measured surface profile deviates from the glass sphere for a surface slope greater than ϕ=40°. This is not predicted by the geometrical model (critical surface slope predicted is 53°) and will be investigated in detail in further work using light propagation models.

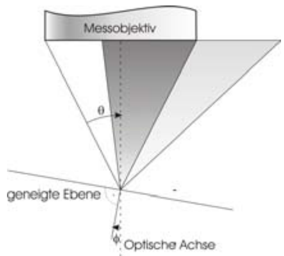

***Fig. 2.1** Reflection at a tilted plane. Only the dark gray part of the reflection cone can re-enter the objective*

Experimental results have also shown that edges with a slope that cannot be resolved by the microscope lead to a wrong evaluation of the surface height. Surface profiles including steps, especially in white light microscopy, are a concern if the step height is shorter than the coherence length of the light source of the interferometer which causes “batwings”. This is also shown theoretically in [3].

Other critical structures are periodical structures with a periodicity smaller than the resolving power of the microscope or structures (e.g. sinusoidally shaped) which cause stray light to be reflected back into the microscope.

3 Simulation of wave propagation through the optical system

In order to investigate the imaging properties of the microscopes on a theoretical basis, C++ algorithms where implemented to simulate the electromagnetic wave propagation through the microscope. These algorithms are based on Rayleigh-Sommerfeld diffraction integral and propagation of the angular spectrum of plane waves [2]. Fig. 3.1 shows first results of the intensity distribution in the sensor pinhole plane of a confocal microscope (for a detailed description of the microscope see [1]). A plane mirror is used as

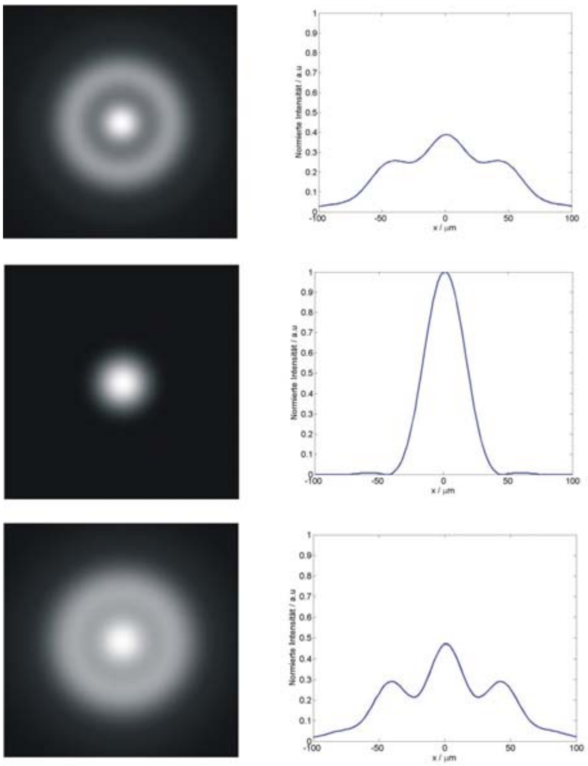

Fig. 3.1 Numerical simulation of the intensity distribution in the pinhole plane of a confocal microscope: (top) mirror 6 µm infront of focal plane of the objective, (middle) mirror in focal plane, (bottomt) mirror 6 µm behind focal plane

a probe. The intensity distribution was calculated for a microscope with a numerical aperture of 0,02 at a wavelength of 633 nm. The model is restricted to paraxial wave propagation where a thin lens approximation can be applied [2].

3 Design of Silicon structures

It has been pointed out [1] that confocal microscopes and white light interferometer differ with respect to structures which lead to artefacts. Hence, the calibration standard must include geometries which take into account each type of optical device. For example, a ramp structure was designed with an increasing step height to investigate the influence of the short coherence of the light source of the white light interferometer.

4 Hot embossing of Silicon structures

For an economic reproduction of the calibration standard the hot embossing maschine HEX 03 (Jenoptik) was used to hot emboss the silicon structurs into plastic. The materials polymethyl methacrylate (PMMA) and polyoxymethylen (POM) were investigated. POM showed a strong structuring of the surface after embossing. Hence, it does not seem to be suitable for a reproduction of the calibration standard. Best embossing results were achieved using PMMA at an ambossing temperature of 130°C and a preasure of 124 bar. Some results are shown in fig. 4.1, where a delta shaped silicon structure was used. For comparing

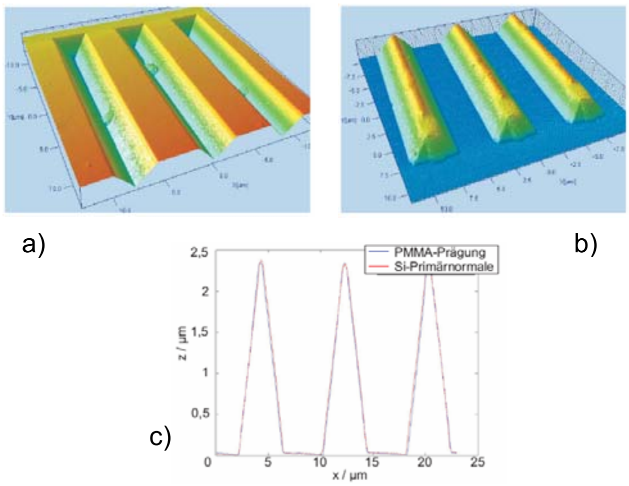

Fig.4.1 a) Silicon structure, b) embossed PMMA structure, c) morphological filtered AFM measurements results for comparing both structures

the silicon original and the PMMA structure AFM measurements were carried out. Fig. 4.1 a) and 4.1 b) show the silicon and the PMMA structure, respectively. Fig. 4.1 c) shows the AFM measurement results after using a morphological filter to take into accout the physical extent of the AFM needle. Both curves show a good agreement.

5 Prospects

The model presented in section 2 is limited to paraxial modelling of the wave propagation. However, in confocal microscopy high numerical aperture objectives are used. Therefore the model will have to be extended to a high-NA model taking into account polarisation effects and aberrations. The effects due to the polychromatic illumination will also need to be considered.

The accuracy of the model will be compared with experimental results taken at a simple set-up.

Based on these results the final calibration standard will be designed and hot ambossed.

Literatur

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